2022 VEHICLE TECHNOLOGIES
ANNUAL MERIT REVIEW

ENERGY EFFICIENT CAVS: WORKFLOW DEVELOPMENT AND DEPLOYMENT

Project ID: EEMS089

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Argonne National Laboratory

Argonne NATIONAL LABORATORY
BERKELEY LAB
INL Idaho National Laboratory
NREL NATIONAL RENEWABLE ENERGY LABORATORY
OAK RIDGE National Laboratory
Pacific Northwest NATIONAL LABORATORY

OVERVIEW

Timeline

- Oct. 2021 - Sep. 2023 (TCF Started in Nov. 2019)
- Percent complete: 50%

Budget

- FY22 Funding:$1,325,000
- FY21 Funding: $1,360,000 (incl. TCF)

Partners

- Argonne National Laboratory (lead)
- George Mason University (partner)
- Clemson University (partner)
- Hyundai (CRADA / industry partner)
- GM, Nissan (stakeholders)

Barriers

- Many CAV technologies are nascent and require models
- Energy-efficiency has not been a factor in the development of Connected and Automated Vehicles (CAVs)
- Lack of methods to evaluate CAV energy benefits
- Lack of practical tools for energy-focused CAV controls development
- Demonstration w/ real vehicles challenging

TCF: US DOE Technology Commercialization Fund
CRADA: Cooperative Research and Development Agreement

RELEVANCE

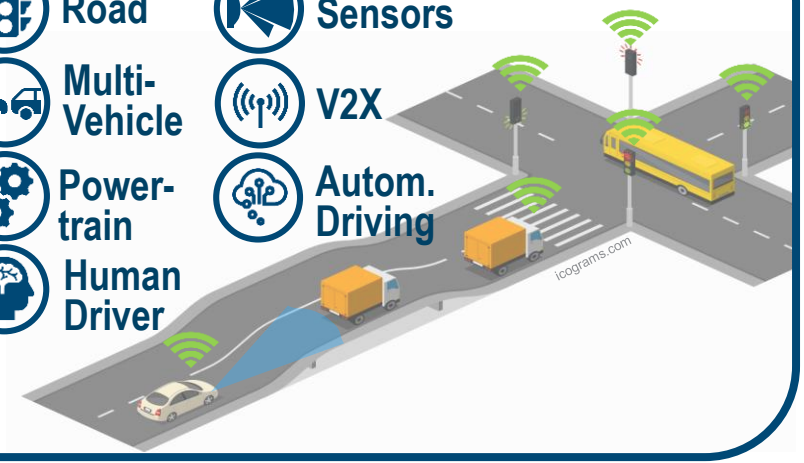
RoadRunner and SVTRIP Essential Tools for SMART Research

ROADRUNNER

- ☑ CAV Eco-driving Control
- ☑ CAV Energy Impacts
- ☑ Predictive Powertrain Control

- ➢ Simulink models
- ➢ Fast & Customizable
- ➢ Graph. interface + API
- ➢ MBSE (Sim. to VIL/XIL)

Road
Multi-Vehicle
Power-train
Human Driver
Sensors
V2X
Autom. Driving



SVTRIP

- ☑ Naturalistic drive-cycle prediction

- ➢ Data-driven
- ➢ In-traffic conditions
- ➢ Flexible Origin/Destination selection (HERE)

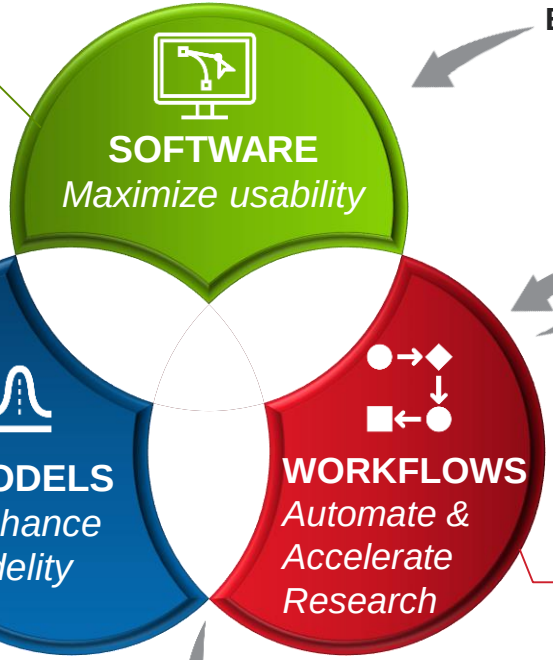
Objectives

- Provide **models** enabling CAV+energy research (incl. SMART)
- Deploy these models to stakeholders in professional **software**
- Add **workflows** that support SMART mobility research

APPROACH

- Integration with AMBER
- Graphical user interface
- Visualization
- Release

EEMS013: AMBER/Autonomie



Hyundai CRADA (data)

EEMS096: Real-world data

EEMS041: Dyno, CAVs, XIL

- Human driver
- Lateral dynamics
- V2X and sensors
- Full CAV model validation

- Exogenous Traffic
- HPC & Calibration
- XIL: real vehicle in virtual environment

Stakeholders

EEMS094
SMART CAV Eco-driving Controls

EEMS093
SMART Mobility workflow

MILESTONES ✓

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY Systems and Modeling for Accelerated Research in Transportation

	FY21Q3	FY21Q4	···	FY22Q4
SOFTWARE		Graphical RoadRunner scenario builder Release of RoadRunner		
MODELS	Human driver data analytics framework operational Lateral movement models in RoadRunner Prototypes of AI algorithms for speed prediction (SVTRIP)	RoadRunner sensor models implemented and integrated		Hyundai driving data processed and analyzed
WORKFLOWS	Deployment of RoadRunner to HPC to enable parameter calibration	XIL workflow demonstration (go/no go)		

ACCOMPLISHMENTS

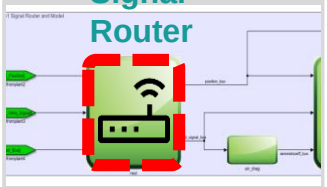
1. Models
2. Workflows
3. Software

LATERAL DYNAMICS IMPACT MODEL

New Model for Impact of Lateral Dynamics (Turns, Curves, Ramps, etc.) on Longitudinal Speed

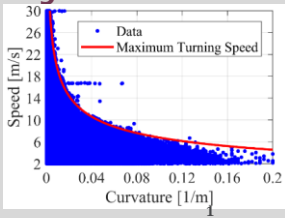
Curvature Signal Extraction from HERE API

Signal Router



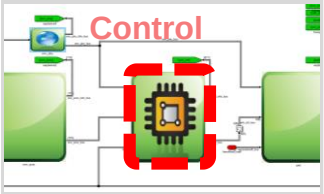
Signal Router and Perception Models Update

Relationship Maximum Speed vs Curvature Using SPMD Dataset

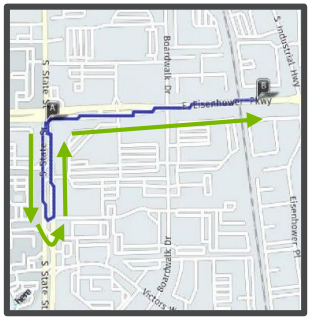


$$v_{max,turn} = \max(5\kappa^{-\frac{1}{3}} - 4, 0)$$

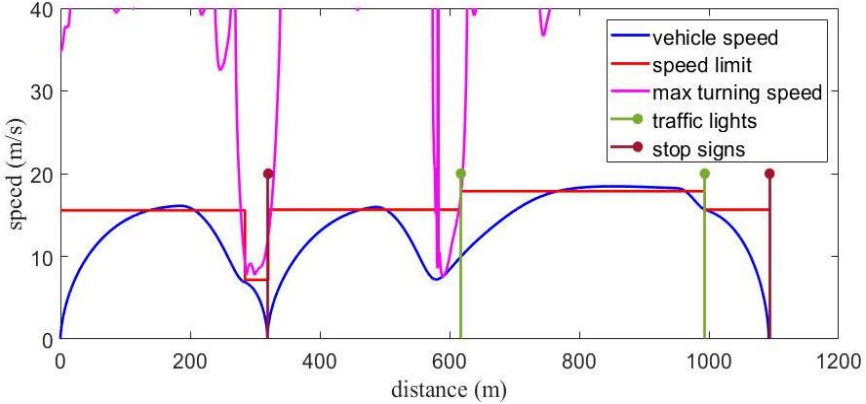
Control



Development of Curvature-aware Vehicle Speed Controller



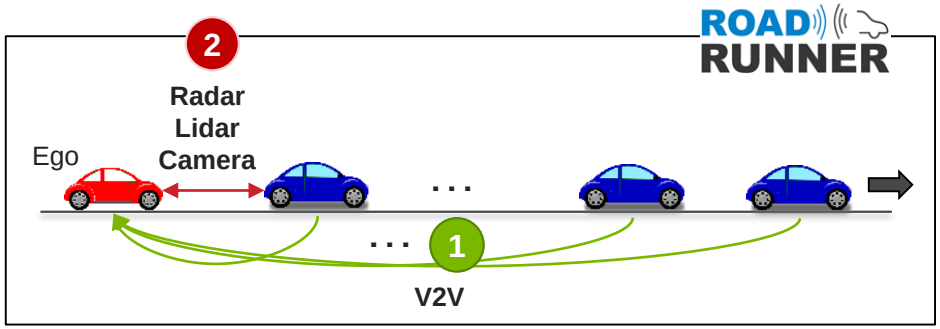
Selected Real-world Route



RoadRunner vehicles are able to adjust their longitudinal speed according to turns and curves.

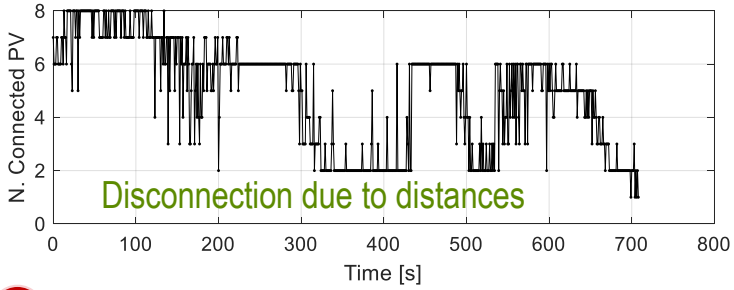
SENSOR & V2V COMMUNICATIONS

Realistic Models for Signal Losses, Inaccuracy, Latency, and other Faults

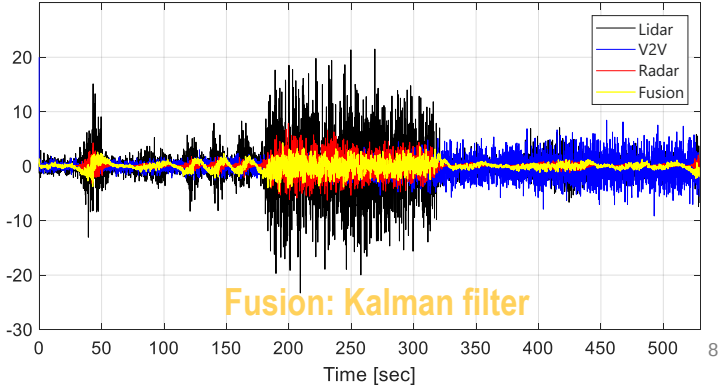


- Communication faults are dependent on physical quantities, e.g., distance b/w agents, relative speed, line of sight blockages.
- V2V: message packet loss, communication latency, and accuracy of messages.
- Radar/Lidar and camera: Signal-Noise-Ratio of perception recall.
- Fusion algorithms to filter & integrate V2V info and sensor measurements.
- Automatic building & implementation in RoadRunner.
- Used in EEMS094 for case studies w/ V2X

1 V2V Connectivity Simulation



2 Sensor Noise and Filtering Simulation



HIGH-FIDELITY HUMAN DRIVER MODEL

Extensive Real-World Driving Data (1M+ km) Obtained from Hyundai to Serve as Basis for New Human Driver Model

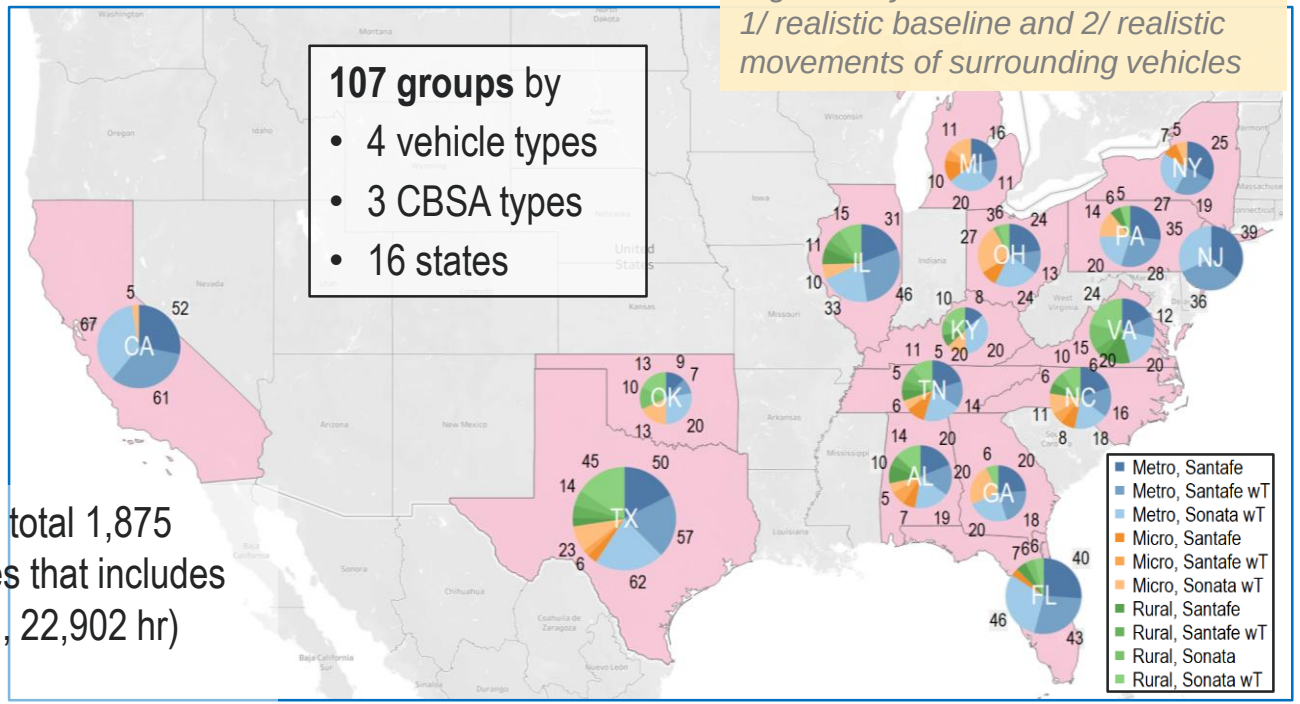
High-fidelity model needed for 1/ realistic baseline and 2/ realistic movements of surrounding vehicles

Hyundai Dataset
All vehicles, All trips

Grouping and Sampling

A list of vehicles of interest

Obtained the customer data of a total 1,875 vehicles across the United-States that includes (total 63,517 trips, 1,052,902 km, 22,902 hr)



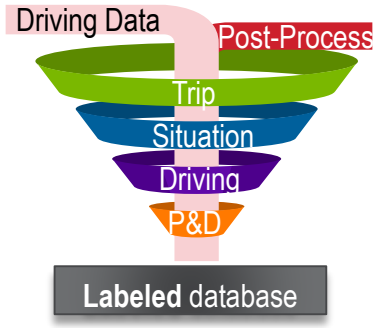
*Core Based Statistical Area *wT = with Turbo

HIGH-FIDELITY HUMAN DRIVER MODEL

Dataset Processed and Analyzed to Provide Insights for Driver Modeling

Data Processing

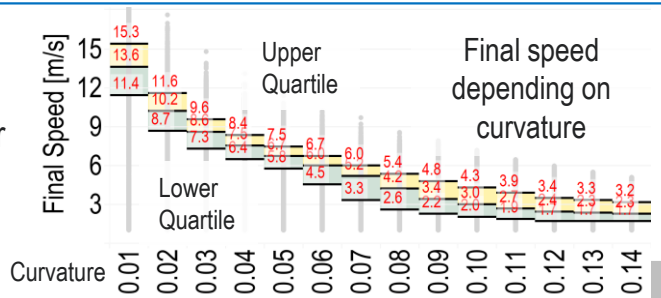
- Segmented all trip data into smaller-scale data (e.g., situation, driving)
- Built a labeled customer driving dataset



Data Analysis

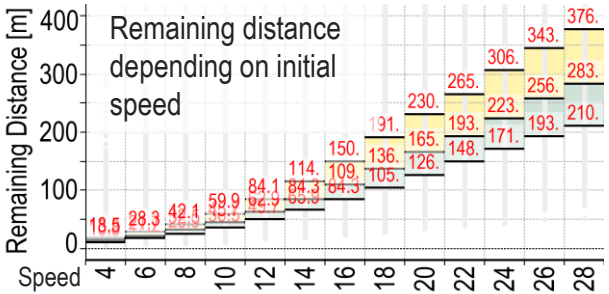
Example 1

A driver decreases the speed lower for turning at higher curvature



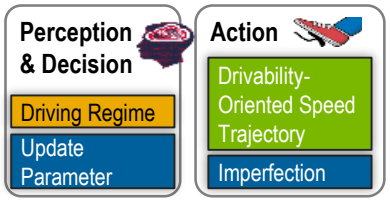
Example 2

Braking starts at longer distance at higher initial speed after coasting



Driver Model

- Use statistical properties of several parameters obtained from data analysis:
  1) "Perception & Decision" (e.g. braking start timing)
  2) "human imperfection" (e.g., perturbed acceleration)
- To be used in **EEMS094**



ACCOMPLISHMENTS

1. Models
2. **Workflows**
3. Software

LINKAGE WITH TRAFFIC FLOW

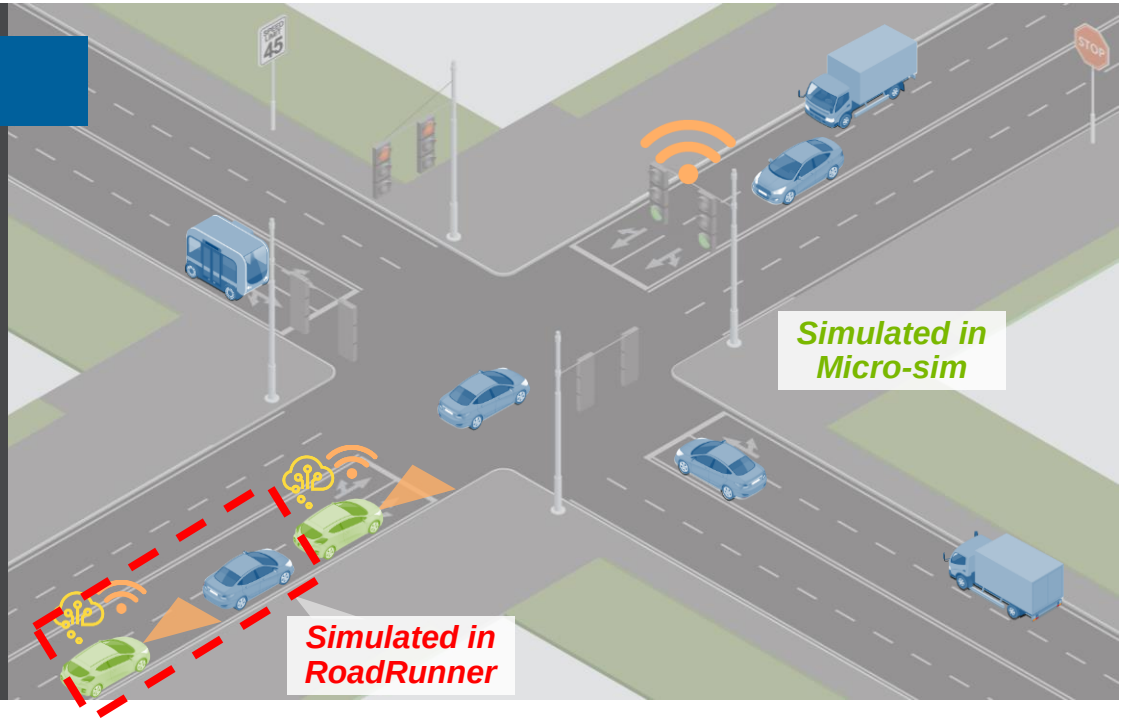
Simulating Traffic Situations with Greater Fidelity

100% Simulation, 2 tools

A few vehicles are modeled in **RoadRunner**

Environment, other vehicles traffic dynamics are simulated in **traffic flow micro-simulator** (SUMO, Vissim or Aimsun).

Supports case studies w/ traffic in **EEMS94**

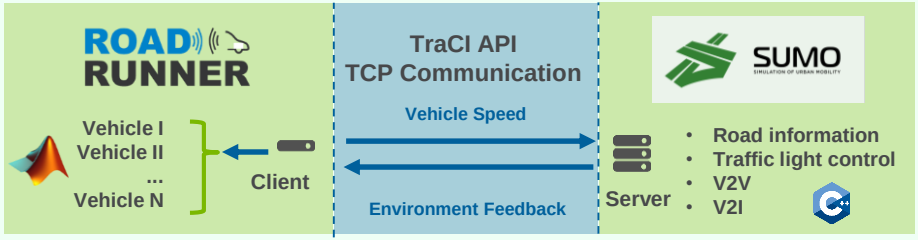


LINKAGE WITH TRAFFIC FLOW

Developed Two Ways of Integrating RoadRunner Vehicles in Traffic

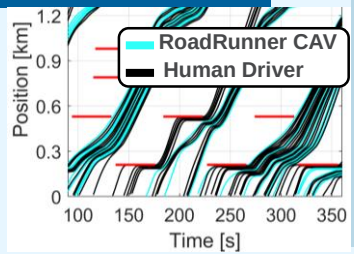
❶ Co-Simulation, e.g. SUMO

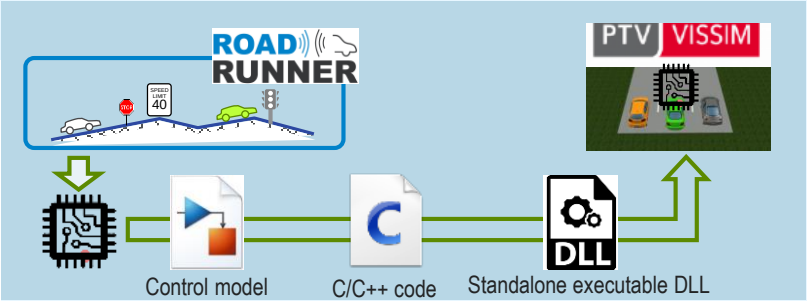
- Both tools run at the same time
- For **refinement** of CAV controls, w/ more realistic traffic situations



❷ Compiled Code Integration, e.g. VISSIM

- All simulation in micro-sim, w/ RoadRunner compiled vehicles
- Scale-up for **traffic flow impacts** (e.g. 40% penetration)



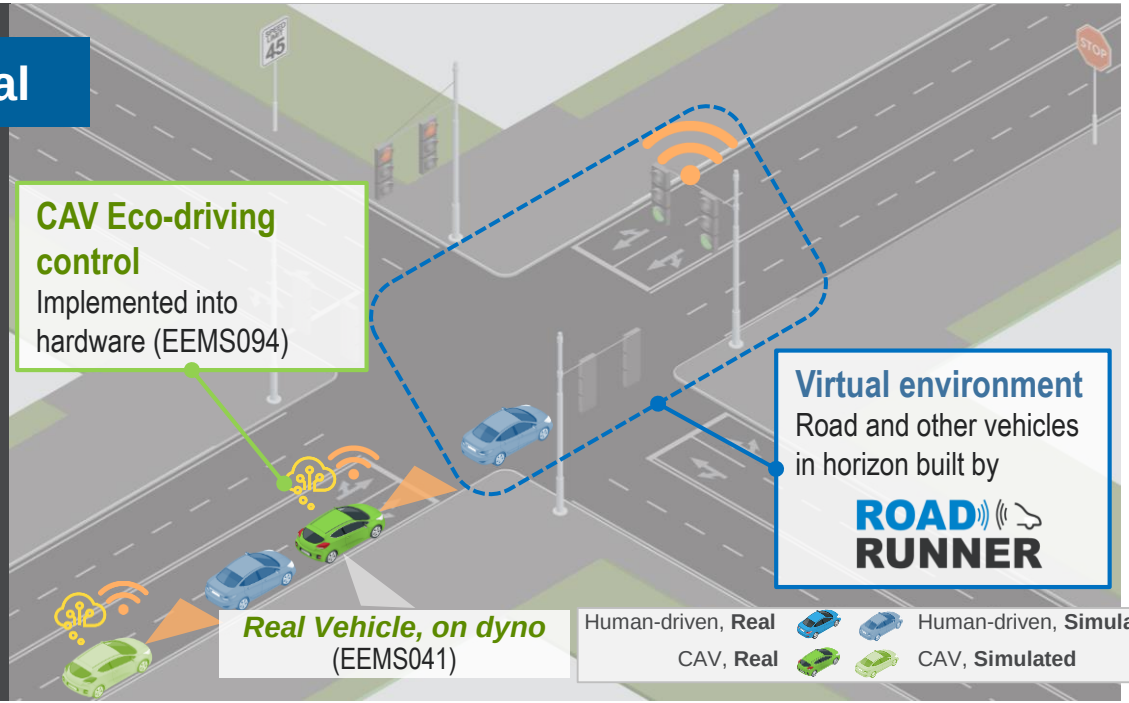


CHASSIS-DYNO XIL WORKFLOW

For Rapid, Repeatable CAV Control Demonstration and Energy Impact Measurement

1 Real Vehicle, Rest Virtual

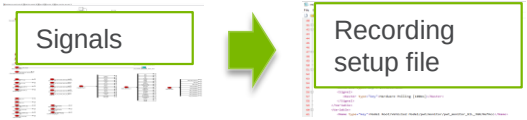
- One actual CAV is on dyno
- Other vehicles and signals are simulated in a virtual world
- Dyno XIL workflow enables rapid, repeatable CAV control testing
- Enables measurement of energy impacts on a real powertrain
- Enables research in **EEMS094**



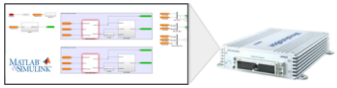
CHASSIS-DYNO XIL WORKFLOW

Made XIL Workflow Faster and more Robust through Automation and Standardization >> Case Study w/ 84 tests (~10h) Executed in just 3 days

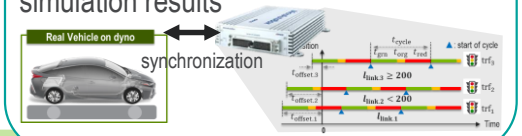
Automated signal recorder (saves 10-20 mins) → Faster preparation and less human error



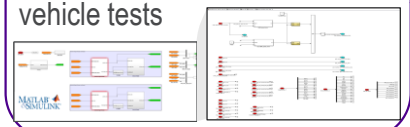
Automated RT target generation (save few mins) → Faster preparation and less human error



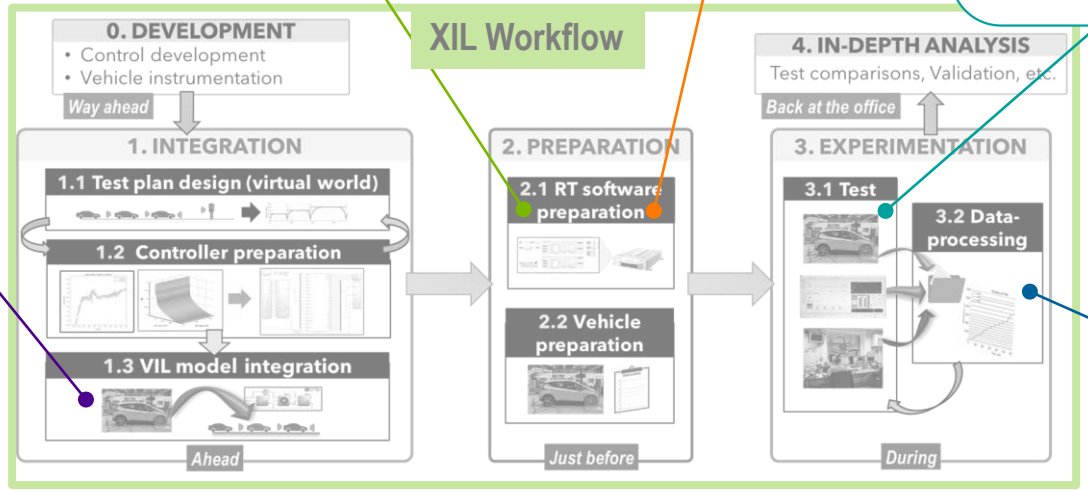
Improved time sync. between virtual world and hardware → Faster test setup, better sync. between test and simulation results



Signal naming re-organization for multi-vehicle tests → Easier analysis for multi-vehicle tests



XIL Workflow



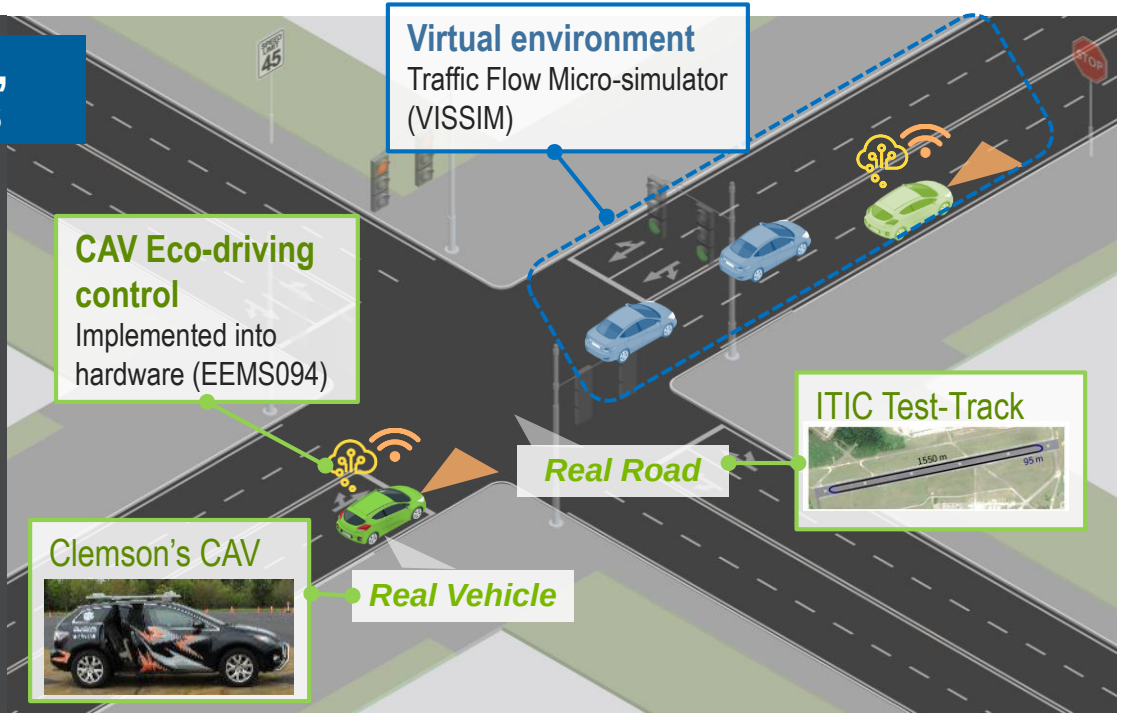
Linkage to AMBER post-process (save few hours) → Faster and reliable analysis

ON TRACK-XIL W/ VIRTUAL TRAFFIC

For CAV Eco-Driving Controls Evaluation and Validation under Virtual Traffic conditions

1 Real Vehicle, Real Road, Virtual Traffic and Signals

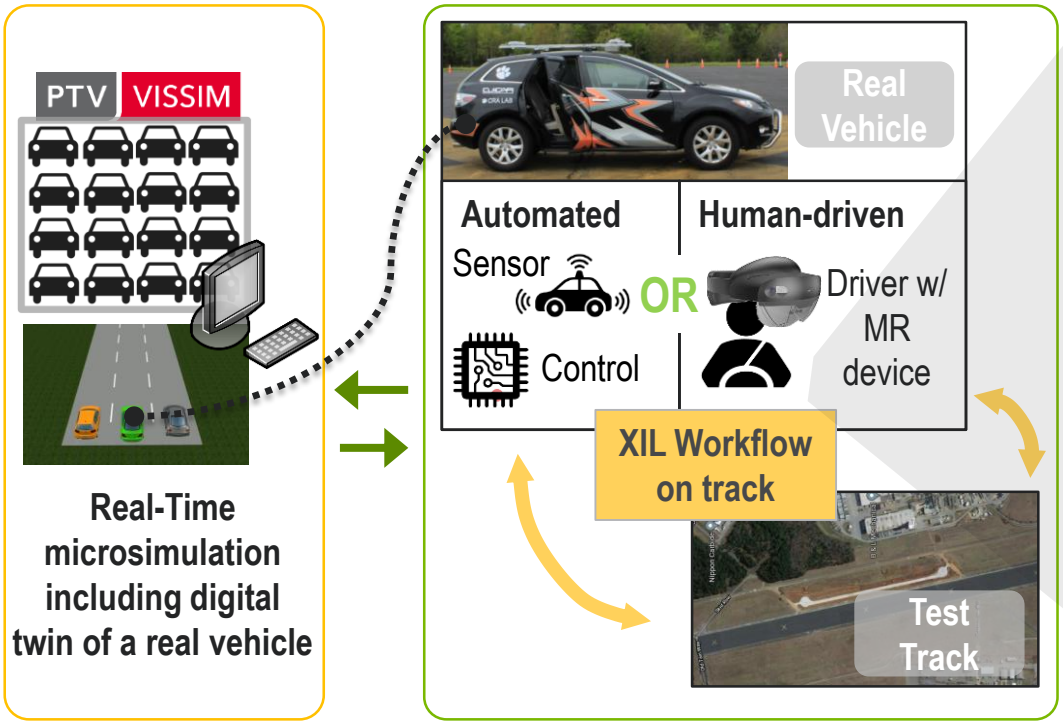
- The real CAV is now driven on a real road (track)
- Other vehicles and signals are simulated by VISSIM
- Argonne high-level eco-driving algorithm controls the Clemson's experimental CAV with a robot driver system as if it was driven in the virtual VISSIM world
- Clemson PIs: A. Vahidi, Yunyi Jia
- Supports Research in **EEMS094**



ITIC: International Transportation Innovation Center

ON TRACK-XIL W/ VIRTUAL TRAFFIC

Developed Workflow for Testing CAVs or Human-Driven Vehicle Mixed-Reality Enables Realistic Visualization of Virtual Traffic



Vehicle-In-Loop MR Projection

Video by Rongyao (Tony) Wang [Clemson]

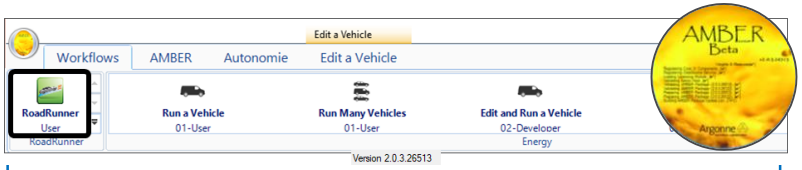
ACCOMPLISHMENTS

1. Models
2. Workflows
3. **Software**

ROADRUNNER RELEASED

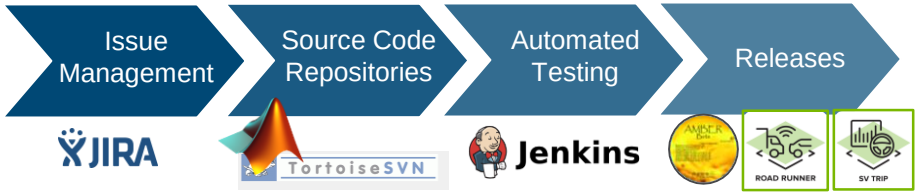
RoadRunner Integrated as a Workflow in the AMBER Beta Release

⇨ An Easy-to-Install and Easy-to-Use Software



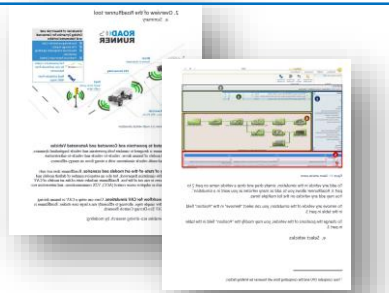
- Installation and licensing through AMBER
- AMBER: also used for Autonomie
- 21 vehicles models released : combination of 7 powertrains and 3 vehicle controllers (Human, IDM, and CAV with V2I)

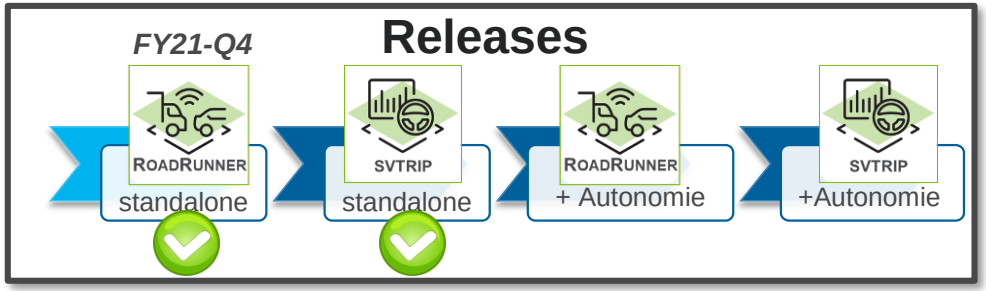
Formalized Software Lifecycle



Documentation

- Training material describing step-by-step instructions



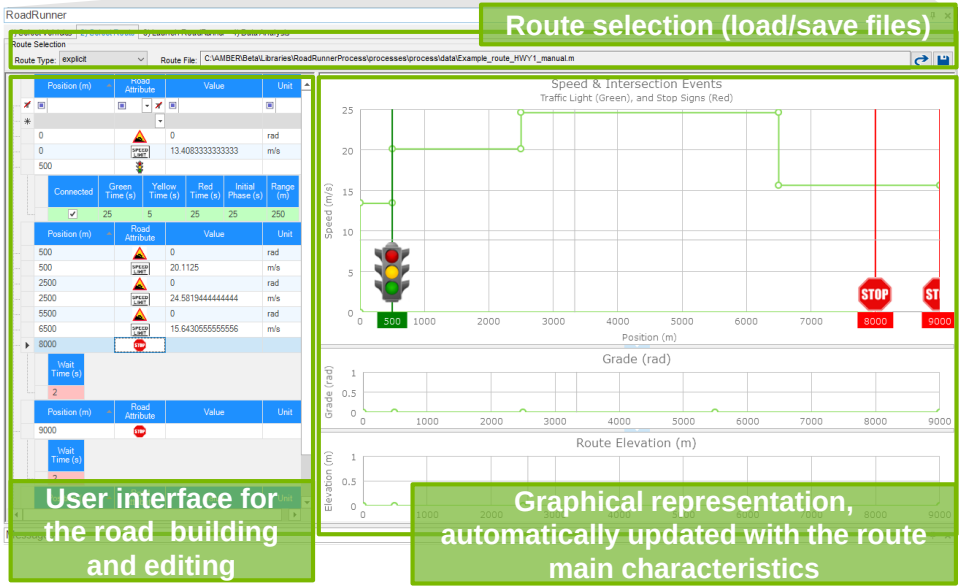


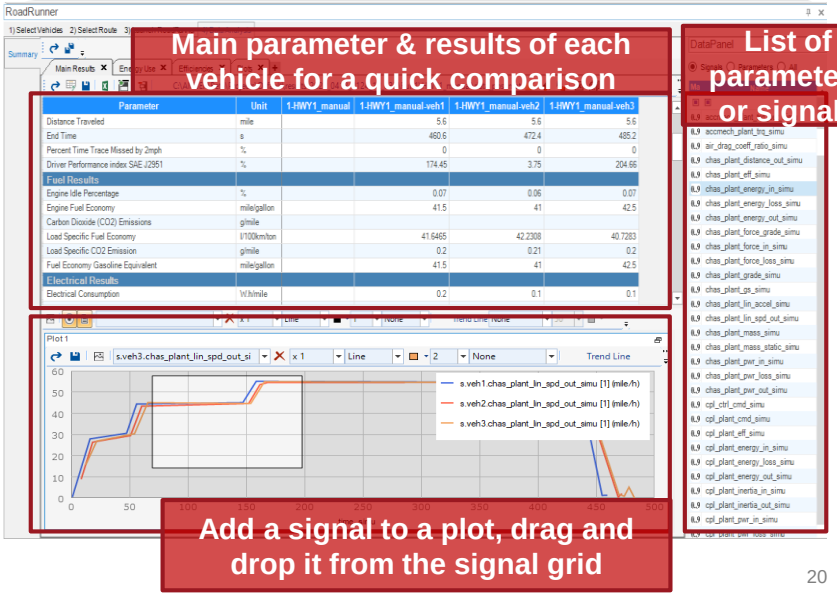
ROADRUNNER - COMPREHENSIVE GUI

Developed an Interface within the AMBER GUI for Graphical: Road/ Scenario Builder, Simulation Results Analysis

RoadRunner workflow

1. Select vehicle
2. Select route
3. Launch RoadRunner
4. Data analysis





CONCLUDING REMARKS

RESPONSES TO PREVIOUS YEAR REVIEWERS' COMMENTS

Reviewer Comment	Response
"Energy efficiency has not been a primary motivator for companies developing AVs. There is significant potential to improve energy efficiency […]. This project is developing the tools and workflow to understand these aspects" *"[…] successfully addresses gaps in the study of CAV technologies"*	Thank you! "CAV+Energy" space is indeed a core focus for RoadRunner development
"Successful collaboration with an OEM to obtain data for model validation" *"Proving out the driver model simulation results with real vehicle testing is very valuable"*	Thank you! OEM data is indeed very valuable for model validation
"Perhaps more data from vehicles with higher levels of autonomy could help improve the models further."	We are limited to vehicles in production or pre-production. With data from EEMS096, Validation of GM's Supercruise is on-going; Tesla's will follow.
"How does ANL balance the requirements of software support and executing DOE projects?"	Making these tools "professional" (reusable, robust, etc.) greatly facilitates ANL's research (EEMS094), while also benefiting other stakeholders.

COLLABORATIONS

Organization	Role
George Mason University	AI for calibration and driver modeling (SVTRIP). – *Vadim Sokolov*
Clemson University	Extension of XIL capabilities to on-track testing – *Ardalan Vahidi, Yunyi Jia*
Hyundai	*[CRADA]* Provides real-world data for human driver model development and validation, will use driver model
ANL/NREL	We use real-world CAV data from **EEMS096** to develop CAV-related models in RoadRunner
GM	Stakeholders for XIL and RoadRunner workflow
Nissan	*[SPP]* Adopting SVTRIP for online, in-vehicle applications

SMART project partners

TCF industrial partner

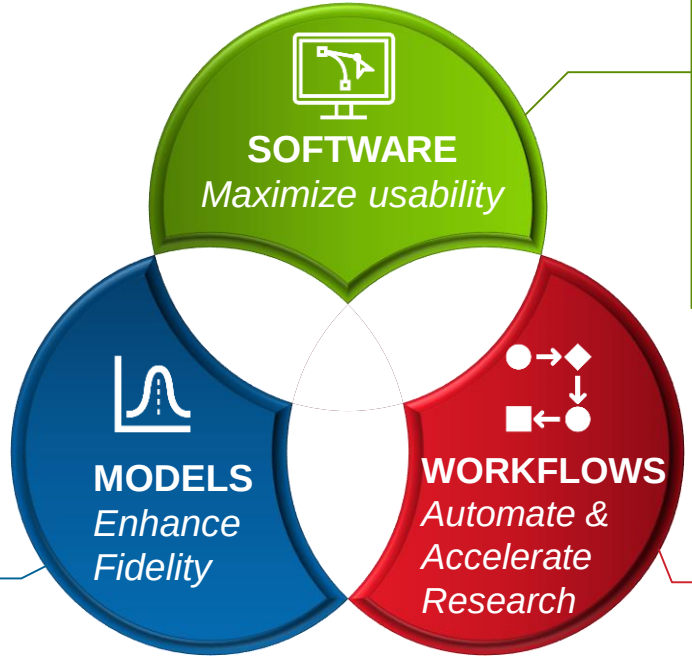
SMART

Stakeholders

This project also relies on other EEMS projects in which we are involved:

- **EEMS094:** CAV control development; uses tools developed here;
- **EEMS013**: AMBER development (backbone for RoadRunner);
- **EEMS041**: XIL hardware, advanced workflow development.

FUTURE RESEARCH



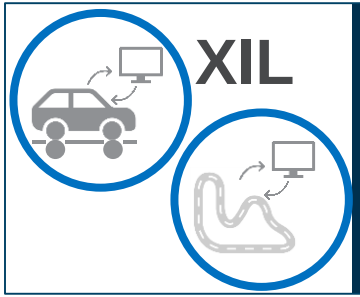
- **Deploy** tools and workflows to stakeholders (2022 release)
- Develop a **visualization** module to replay simulations on a road map and synchronize with time-series data
- Integrate **new workflows** in GUI, including integration with traffic micro-simulation

- **Multi-lane** simulation
- Complete light-duty vehicle **human driver** model
- **Validate CAV models** (Data from EEMS096); first vehicle will be GM's SuperCruise
- Integrate **AI-based speed prediction** algorithm (SVTRIP)

- Integrate exogenous **traffic** with RoadRunner (e.g., automate connection with traffic flow microsimulation)
- Enhance **XIL workflow** (e.g., integrate direct vehicle override controls, add grade/aero emulation, expand process automation…)
- Develop **AI-based control calibration** process

Any proposed future work is subject to change based on funding levels

SUMMARY

SVTRIP	*SVTRIP migrated to Python; promising AI-based algorithms should result in a "SVTRIP-AI" by FY23.*
ROADRUNNER *Release, Models, Workflows*	▪ ***RoadRunner released*** *(beta): w/ professional GUI, a graphical scenario builder, w/ training materials. Software lifecycle in place.* ▪ *Improved* ***RoadRunner models****: V2X communications, sensors, lateral movements impact on longitudinal speed.* ▪ *Strong progress on* ***human driver modeling****, w/ 1M+ km of real-world data*
	▪ *Dyno-based* ***XIL workflow operational****; continuous improvements to make it faster, more flexible, more robust.* ▪ *E.g. 84 tests (~10 hours) executed in 3 days only* ▪ *Developed new* ***XIL workflow for on-track*** *testing; features ROS, virtual micro-sim traffic and mixed-reality goggles*
Supporting SMART Mobility R&D	*All new developments and features support CAV research, and will be progressively deployed to stakeholders*

EEMS089

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

ENERGY EFFICIENT CAVS: WORKFLOW DEVELOPMENT AND DEPLOYMENT

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FOR MORE INFORMATION
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THANK YOU!

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TECHNICAL BACK-UP SLIDES

DYNO XIL: EXPERIMENTAL SETUP

Real-time SOFTWARE
(dSpace Micro-Autobox)

Real Time CAN Connection

Vehicle States
(Speed, SOC, etc.)

Automated Driving Controller

Perceived Environment

APP, BPP Demand

Robot Driver Controller

Virtual Environment

Send Commands/Monitor Feedback

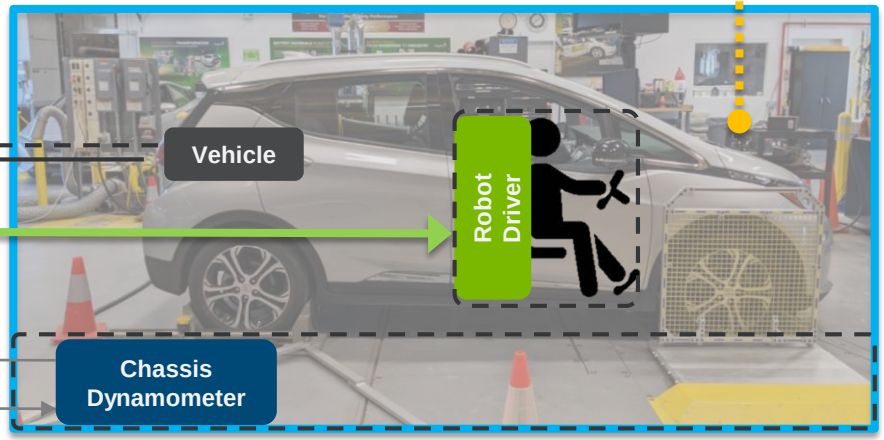
Control Room with dedicated HMI

Vehicle Info

APP [V]
BPP [V]

Speed

Grade/aero load

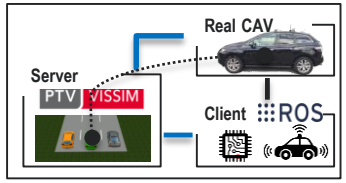


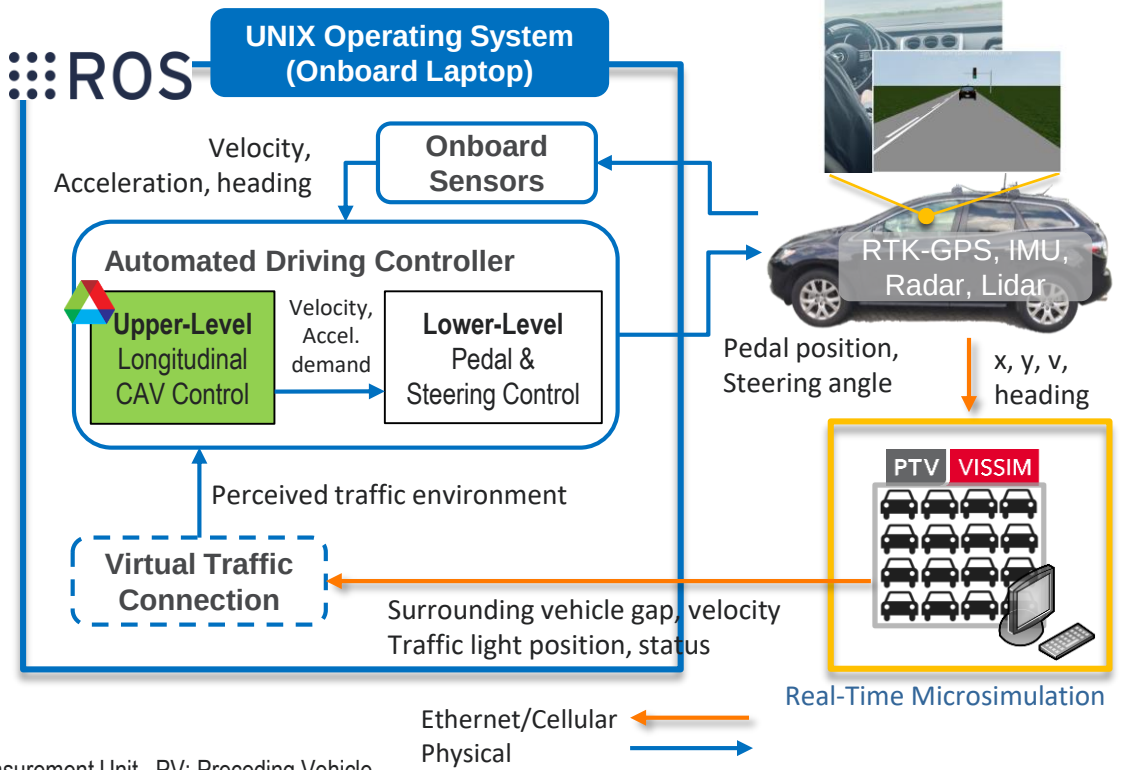
CAN | Analog | Ethernet

TRACK-XIL: CAV TEST SETUP

For the Evaluation of Real CAV Energy Impacts for Various Virtual Scenarios

- RTK-GPS and IMU sensors
- Virtual PV sensors
- Virtual V2X connectivity
- Lower-level control for speed tracking
- Automated driving controlled by V2X-enabled eco-driving controller:
  - Utilize preview information about surrounding environments
  - Compute reference trajectories over preview horizon





RTK-GPS: Real-time Kinematic-Global Position System, IMU: Inertia Measurement Unit , PV: Preceding Vehicle